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## MBA PROFESSIONAL REPORT

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### LOCATION OPTIMIZATION OF MOBILE COLD-FORMED STEEL SYSTEMS TO PROVIDE HUMANITARIAN RELIEF AFTER NATURAL DISASTERS

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December 2015

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**LOCATION OPTIMIZATION OF MOBILE COLD-FORMED STEEL SYSTEMS  
TO PROVIDE HUMANITARIAN RELIEF AFTER NATURAL DISASTERS**

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Submitted in partial fulfillment of the requirements for the degree of

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# **LOCATION OPTIMIZATION OF MOBILE COLD-FORMED STEEL SYSTEMS TO PROVIDE HUMANITARIAN RELIEF AFTER NATURAL DISASTERS**

## **ABSTRACT**

Cold-formed steel mobile factory (CFSMF) is a rapid self-contained system that produces members from rolled steel. The unit essentially provides a mobile framing construction system that can be used for construction of temporary, recyclable structures. These structures can be used for humanitarian assistance, disaster relief, and military contingency operations scenarios. CFSMF also provides benefits by reducing reliance on local economies' resources in natural disaster affected areas and areas that have internally displaced or emigrating persons for various reasons. This project discusses the benefits and potential uses of CFSMF and recommends global locations to base these units.

The 10 countries discussed in the case study have the highest need of such systems based on United Nations natural disaster data. The level of diplomatic relations of the 10 countries with the United States is gauged by the cumulative economic aid they received from the United States Agency for International Development (USAID) over a 10-year period. The recommended locations are determined by an integer programming optimization model. The model solution proposes an allocation method for CFSMF systems. The model can also be used for similar types of aid.

The case study in this report uses a small number of countries in order to simplify the mathematical model. It can be scaled up to reflect a larger set of countries, as well as additional types of constraints.

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## LIST OF ACRONYMS AND ABBREVIATIONS

AISI	American Iron and Steel Institute
CAD	computer aided design
CCP	casualty collection points
CFS	cold-formed steel
CFSMF	cold-formed steel mobile factory
CRED	Centre for Research on the Epidemiology of Disasters
DOD	Department of Defense
DRC	disaster recovery center
EM-DAT	Emergency Events Database
HA/DR	humanitarian assistance and disaster relief
IP	integer programming
NGO	nongovernmental organization
UN	United Nations
UNSD	United Nations Statistics Division
USAID	United States Agency for International Development

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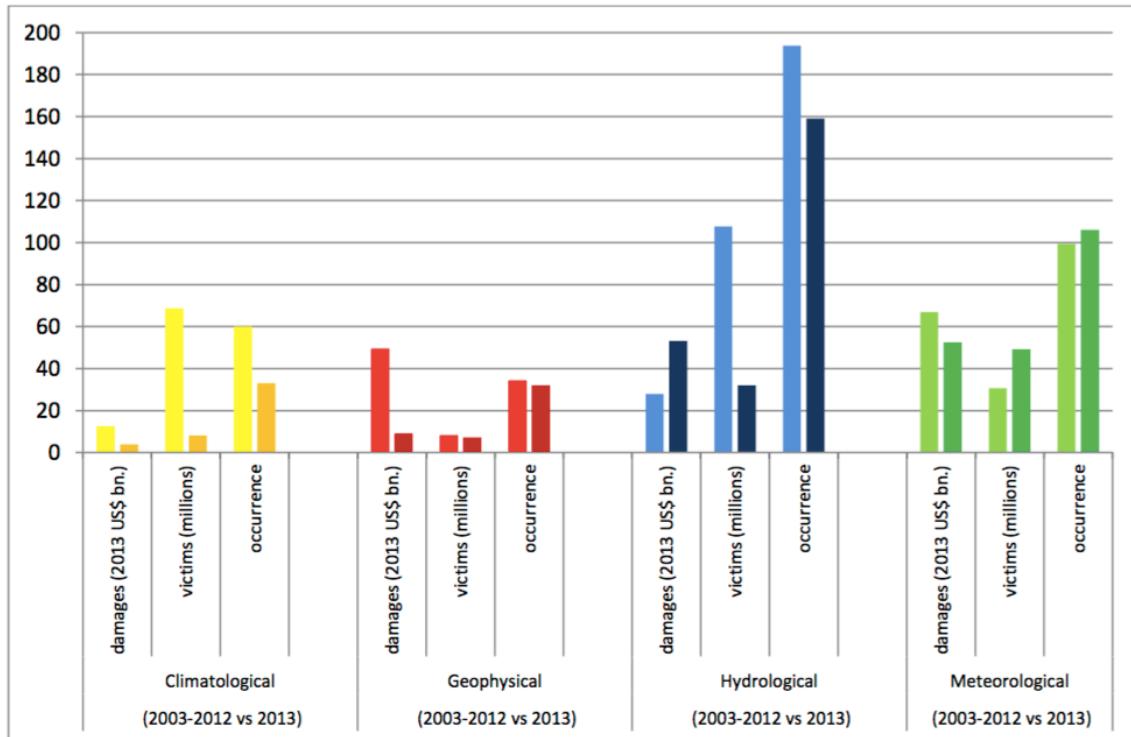
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## I. INTRODUCTION

### A. NATURAL DISASTERS

The Centre for Research on the Epidemiology of Disasters (CRED) defines a disaster as “a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering.” Examples include “floods, volcanic eruptions, earthquakes, tsunamis, and other geologic processes” (“Natural Disaster,” n.d.). Severity of the events are measured in economic loss, ability to rebuild and lives lost (Basic Planet, 2013). Natural disasters affect tens of millions of people, and cost tens of billions of dollars annually (see Figure 1).

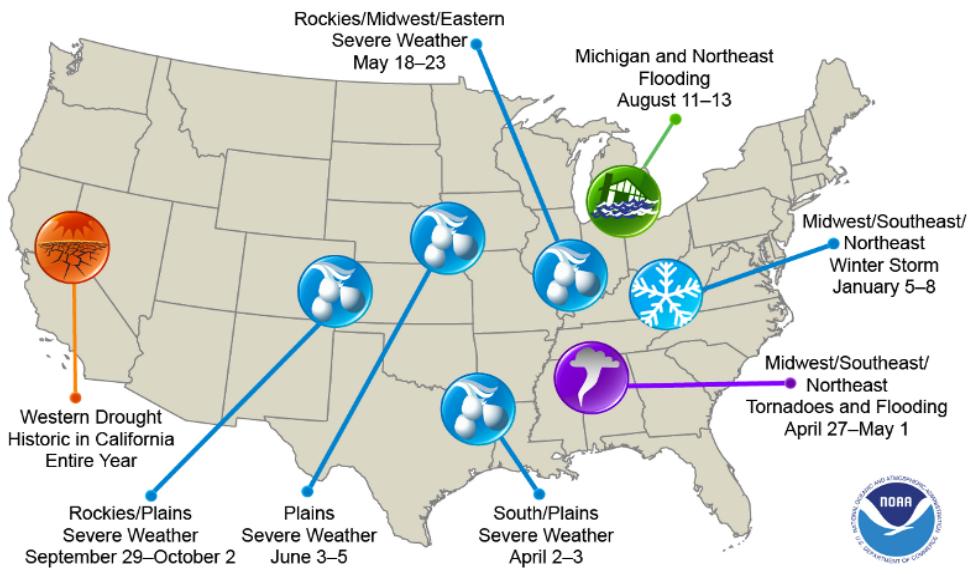
Figure 1. Natural Disaster Impacts by Disaster Subgroup, 2003–2012  
Annual Average versus 2013



Source: Guha-Sapir, D., Hoyois, P., & Below, R. (2014). Annual disaster statistical review 2013, the numbers and trends. Brussels: Centre for Research on the Epidemiology of Disasters. Retrieved from [http://www.disasters.ir/files/ADSR\\_2013.pdf](http://www.disasters.ir/files/ADSR_2013.pdf)

In 2014, the United States experienced eight natural disasters with financial losses of at least one billion dollars (see Figure 2) (National Centers for Environmental Information, n.d.).

Figure 2. U.S. 2014 Billion-Dollar Weather and Climate Disasters



The data on natural disasters used in this report was retrieved from the United Nations Statistics Division (USND) Environmental Indicators repository (“Environmental Indicators,” 2010). Country specific data regarding persons affected from various types of natural disasters is analyzed and the data is then used to influence decisions regarding allocation of cold-formed steel mobile factories (CFSMF) (see Figure 3) to affected countries.

## B. COLD-FORMED STEEL

Cold-formed steel (CFS) is a process where structural members are manufactured from steel sheeting that is shaped by roll forming machines (see Figure 4) at ambient temperatures and allows for high speed production and consistent quality of the members

(Cold-formed steel in building construction, 2010). CFS has its beginnings traced back to the California gold rush when Peter Naylor advertised “portable iron houses for California” (History, n.d.). Lustron Homes, an early mass manufacturer founded by Carl Strandlund, manufactured homes in the 1940s and sold about 2,500 homes with steel framing (History, n.d.). Two of the benefits of cold-formed steel are its cross-sections ability to maintain consistent thickness and its ability to carry heavy loads (History, n.d.).

Figure 3. FRAMECAD Cold-Formed Steel Mobile Factory



Courtesy of Brian Steckler, Department of Information Science, Naval Postgraduate School.

Figure 4. FRAMECAD Cold-Formed Steel Machine; Warehouse Configuration



Courtesy of Brian Steckler, Department of Information Science, Naval Postgraduate School.

The American Iron and Steel Institute (AISI), sponsored design specification development in 1939 and called upon George Winter of Cornell University (History, n.d.). His first published reports compiled the first edition of the AISI's "Specification for the Design of Light Gage Steel Structural Members" (History, n.d.).

Cold-formed steel features superior chemical and physical qualities that give it a broad range of advantages over other framing materials. According to the Steel Framing Industry Association, the advantages of cold-formed steel framing over other framing materials include the following:

**Strength:** Steel has the highest strength-to-weight ratio of any building material. Moreover, the strength of cold-formed steel also provides

architects with greater flexibility, allowing designs that incorporate longer spans and other architectural features.

**Durability:** Steel is inorganic, and thus impervious to termites, rot and mold. A protective layer of zinc and other metallic coating provides long-term durability that research demonstrates can last hundreds of years without any deterioration.

**Stability:** Due to its consistent chemistry, steel behaves in a highly predictable manner when subjected to the structural loads and stresses imposed by high wind and seismic forces. Because steel cannot absorb moisture, its use also eliminates most of the expansion and contraction of construction materials that produces cracks, warps, and other defects in both internal and external finishes.

**Non-combustibility:** Steel does not burn and will not contribute to the spread or intensity of a fire. Because of this, cold-formed steel projects can easily be designed to meet fire code rating requirements. Non-combustible structures, like those built with cold-formed steel framing, have a better loss history than combustible wood framing. This often translates into lower costs and broader coverage for many types of construction insurance.

**Sustainability:** Steel is the only building material that is infinitely recyclable. As a recognized green building material, cold-formed steel framing projects can earn credits for green building ratings such as LEED and similar programs.

**Cost-effectiveness:** Cold-formed steel offers cost savings on a number of fronts. By helping to minimize fire risk, the use of cold formed steel results in lower insurance costs for builders and owners. Additionally, panelized cold-formed steel construction methods produce shorter construction cycles, allowing builders to complete steel-framed projects months faster than with other framing materials. Finally, framing with cold-formed steel generates far less material waste than traditional wood framing. (Steel Framing Industry Association, n.d.)

While many advantages make CFS a desirable construction method for humanitarian assistance and disaster relief (HA/DR) purposes, it does have its disadvantages as well. The FRAMECAD unit that Tully and Skidmore (2015) evaluated costs \$421,000 (maintenance, support, spare parts, software, and training included in the figure), and is integrated into a 20-foot container box that requires transportation with heavy lift capability. The cost, weight, and shipping of the steel used by the machine must be taken into consideration, as well, as it will be incurred many times over the life

of the system. The high costs may be a limiting factor for government and non-government organizations that can benefit from the procurement of CFS systems.

Tully and Skidmore (2015) discuss utilizing cold-formed steel mobile factories in support of logistics in HA/DR operations. They suggest that CFSMF systems' capabilities decrease logistical burdens. In the wake of a disaster, reliance on local economies should be minimized. While re-building an economy, CFSMF systems can alleviate the struggles of local populations and ensure remaining natural resources are put to use for the host nation. Tully and Skidmore propose to conduct further research in order to determine the quantity and optimal locations of CFSMF systems globally.

### **C. RESEARCH QUESTIONS**

This thesis proposes a methodology that can be used as part of U.S. aid to countries affected by natural disasters. It is suggested here that the U.S., through the Department of Defense (DOD) or nongovernmental organizations (NGO), fund permanently stationed cold-formed steel mobile factories in countries that are significantly affected by natural disasters. This will enable the affected countries, DOD or NGOs to construct structures quickly and locally in the aftermath of a natural disaster.

The DOD and U.S. NGOs will benefit from the versatility of CFSMF. The CFSMF can be used to build; logistics support centers, barracks, operations centers, warehouses, and other structures to support areas affected by the natural disasters or for use at a base or staging location outside of the United States where DOD or NGOs have a presence.

Therefore, this report focuses on determining the optimal global quantities and locations of mobile CFSMF, such that the impact of these units is maximized over the areas on earth affected by four natural disaster categories (climatological, geophysical, hydrological, and meteorological) ("Environmental Indicators," 2010). The main factor affecting the quantity and allocation decisions for CFSMF systems is the number of persons affected by natural disaster events in each country. Additional modeled considerations include the level of diplomatic relations with the aided countries,

countries' own CFSMF availability, and logistics capabilities that allow sharing of CFSMF units among neighboring countries.

Specifically, this research intends to answer the following question: assuming that the U.S. is planning to directly purchase, through the DOD or provide economic aid to NGOs to purchase, a given number of cold formed steel mobile factories in foreign countries affected by natural disasters, what is the optimal quantity of CFSMF units allocated to each country considering the factors listed above?

#### **D. METHODOLOGY**

This report focuses on determining the optimal global allocation of CFSMFs, such that the impact of these units is maximized over the areas on earth affected by the four natural disaster categories. The factors affecting the quantity and location decisions for the CFSMF systems are as follows:

- the number of persons affected by natural disaster events in these locations
- the current level of aid to these countries
- the countries' own CFSMF availability
- the possibility of sharing CFSMF units among neighboring countries

It is important to note that the natural disaster data on affected persons in countries that have recorded natural disaster data is assumed to be non-overlapping. Therefore, if one type of natural disaster affected 100 persons and another type of natural disaster affected 200 persons, then the total number of affected persons is 300.

The countries affected by natural disasters of the four natural disaster categories in the 10-year period 2000–2009 were sorted by the number of persons affected by these disasters in descending order. The 10 countries with the highest number of persons affected were selected as a case study for analysis and modeling in this thesis.

The United States Agency for International Development (USAID) total economic aid to the 10 selected countries were rated such that the country receiving the most funds received a rating of 10. The remaining countries received a normalized rating.

Integer programming optimization models are often used to determine optimal allocation of limited resources. In order to determine the optimal allocation of a limited number of CFSMF units to the 10 countries an integer programming optimization model was developed.

Assumptions regarding availability of CFSMF units in each country and neighboring relationships that allow sharing of CFSMF units added constraints to the optimization model.

## II. DATA

### A. NATURAL DISASTER DATA

The natural disaster data was retrieved from the United Nations Statistical Division (USND) Environmental Indicators repository (“Environmental Indicators,” 2010). The source data is compiled by CRED and is maintained in the Emergency Events Database (EM-DAT). The UNSD Environmental Indicators website page divides natural disasters into four categories; climatological, geophysical, hydrological, and meteorological.

The following parameters from EM-DAT apply to all four natural disaster categories. According to the source data, “only disasters that fulfill at least one of the below criteria are included in EM-DAT” (“Climatological Disasters,” 2010):

- ten or more people reported killed
- one-hundred or more people reported affected
- declaration of a state of emergency
- call for international assistance

“Persons affected,” is the number of total affected according to the EM-DAT definitions. Total affected is the sum of injured, homeless, and affected. “Injured” is defined as people suffering from physical injuries, trauma or an illness requiring medical treatment as a direct result of a disaster. “Homeless” is defined as people needing immediate assistance for shelter. “Affected” is defined as people requiring immediate assistance during a period of emergency; it can also include displaced or evacuated people. (“Climatological disasters,” 2010)

A ‘0’ in EM-DAT does not represent a value and can mean either that there were no reported events or no information is available. (“Climatological disasters,” 2010)

**Data Quality;** the EM-DAT database is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies. Priority is given to data from UN agencies, governments and the International Federation of Red Cross and Red Crescent Societies. The entries are constantly reviewed for redundancy, inconsistencies and incompleteness. CRED consolidates and

updates data on a daily basis. A further check is made at monthly intervals. Revisions are made annually at the end of each calendar year. (“Climatological Disasters,” 2010)

**Climatological disasters;** are defined as events caused by long-lived/meso to macro scale processes in the spectrum from intra-seasonal to multi-decadal climate variability. Such events are further classified as extreme temperature; drought; wildfire. Extreme temperature events are heat waves, cold waves and extreme winter conditions (snow pressure, icing, freezing rain, avalanche). Wildfire is forest fires and land fires (grass, scrub, bush, etc.). (“Climatological disasters,” 2010)

**Geophysical disasters;** are events originating from solid earth and are classified as, earthquakes (ground shaking and tsunamis), volcanic eruptions, and dry mass movements (rock fall, avalanche, landslide, subsidence). (“Geophysical disasters,” 2010)

**Hydrological disasters;** defined by EM-DAT are events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up. Such events are further classified as, flood (river flood, flash flood, storm surge/coastal flood), and wet mass movement (rock fall). (“Hydrological disasters,” 2010)

**Meteorological disasters;** are defined by EM-DAT as events caused by short-lived/small to meso scale atmospheric processes (lasting minutes to days). Such events are classified as, tropical storms and extra-tropical cyclones (winter storms). (“Meteorological disasters,” 2010)

## **B. ECONOMIC AID DATA**

The economic aid data was retrieved from the United States Agency for International Development Greenbook (Greenbook, n.d.) for the most recent 10-year period (2003–2012). The economic aid data is used in this thesis as a measure of the diplomatic relations between the U.S. and foreign countries. Higher aid indicates not only higher need for aid, but also closer diplomatic relations.

## **C. DATA ANALYSIS**

### **1. Natural Disaster Data**

Natural disaster data from the climatological, geophysical, hydrological, and meteorological categories was deduced from the raw data and consolidated to total persons affected and number of natural disaster events for the 10-year range; 2000–2009.

The consolidated data was then sorted in descending order by number of persons affected. The 10 countries with the most persons affected were selected for the case study in this thesis. These countries are shown in Table 1, along with the total number of natural disaster events for the 10-year period from 2000–2009 and total number of persons affected by these disasters.

Table 1. Countries with Highest Number of Persons Affected by Natural Disasters and Corresponding Number of Events from 2000–2009

Country	Persons Affected	Number of Events
China	1,112,214,506	271
India	598,790,757	153
Bangladesh	71,698,450	63
Philippines	49,768,870	141
Thailand	28,072,184	37
Ethiopia	22,831,949	29
Vietnam	20,316,122	76
South Africa	15,102,150	17
Pakistan	12,363,793	52
Indonesia	10,098,137	137

Adapted from: Environmental Indicators. (2010). Retrieved October 21, 2014 from <http://unstats.un.org/unsd/environment/qindicators.htm>

## 2. Economic Aid Data

The data from each year of the 10-year period (2003-2012) was totaled for the 10 countries listed in Table 1. The 10 countries were then sorted in descending order of aid and listed in Table 2.

Table 2. Corresponding Natural Disaster Countries' Economic Aid Totals from USAID, 2003–2012, in Millions

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Pakistan	322	349	434	629	616	532	1339	2002	759	1138	8121
Ethiopia	721	433	676	322	466	1004	960	989	552	865	6987
South Africa	78	128	185	260	391	566	568	563	490	273	3503
Indonesia	180	151	534	210	236	194	217	323	234	214	2493
Philippines	109	109	98	113	103	127	153	209	586	166	1771
India	176	178	194	170	153	146	143	168	106	174	1607
Bangladesh	102	89	78	82	88	184	168	237	217	247	1492
Thailand	5.2	8.3	19	23	26.1	32.9	36.8	40.8	39.6	45.8	278
China (P.R.C.)	3	1.6	3.1	11.2	24.7	29.5	14.7	40.8	9.7	12.5	151
Vietnam											0

Adapted from: Greenbook. (n.d.). Retrieved April 3, 2015 from <https://explorer.usaid.gov/reports-greenbook.html>

Based on the data analysis of persons affected and total economic aid received, the 10 countries identified are the focus of the case study's integer programming model. The model will demonstrate how CFSMF allocation decisions can be made using the results of the analysis above.

### III. LITERATURE REVIEW

Natural disaster events create havoc, and having the proper assets available is imperative and an integral part of the HA/DR process. A CFSMF is one of those integral parts. The mobile factory has the ability to serve many purposes; command operations, triage facility, food or medicine dispersal center, shelter, etc., all secured within the confines of a CFS structure.

Apte, Heidtke, and Salmerón (2014) propose an optimization model to determine the locations of casualty collection points (CCP) after a nuclear device detonation within a specific geographic area. Their focus is to optimize the CCP locations in order to maximize casualty throughput with specific parameters for such an event for the District of Columbia. Their study stresses the importance of location optimization of CCP facilities as a part of the overall planning for a national security plan.

Dekle, Lavieri Martin, Emir-Farinas, and Francis (2005), utilized an integer programming solution known as a covering-facility-location model to optimize locations for disaster recovery centers (DRCs) in Alachua County, Florida. Their study required that each DRC in Alachua must be within 20 miles of each resident in the county with specific structure, communication, and parking requirements.

Yoho and Apte (2011) discuss a worldwide strategy to effectively and efficiently provide emergency supplies and services for HA/DR efforts after a natural disaster. They investigate prepositioning supplemental resources and preemptive and phased deployment of assets as potential policy options that could be correlated between the policies and disaster classification, which is based on localization of a disaster and speed of onset. Yoho and Apte's (2011) discussion is focused on policies and disaster types.

Caunhye, Nie and Pokharel (2012) classify optimization models in HA/DR operations, which are used in times of emergency logistics. The study identifies classes to include facility location, relief distribution, casualty transportation, and other operations. The authors identify research gaps and propose future directions.

Anderson (1970) discusses the importance of military assistance in natural disasters as the military is seasoned in rapid response. Yoho and Apte (2011) discuss a related expertise of the U.S. military to aid in conflict response and prepositioning. Both prepositioning and quick response are hallmarks of U.S. military operations.

Sobel and Leeson (2007) discuss centralized information in disaster relief as a factor in the relief success or failure. CFSMF systems allow users to incorporate fragmented information (Sobel & Leeson, 2007) to meet the current needs of HA/DR efforts. Fawcett and Fawcett (2013) discuss the systems design aspect of HA/DR supply chains, moving, eventually, to a synchronized supply chain from a temporary one to increase effectiveness.

Balcik and Beamon (2008) utilize a covering location model to determine where to locate facilities in a HA/DR supply chain. Much like this study, their research determines the optimal quantities and locations of distribution warehouses. Their study also determines optimal quantities of specific supplies in the centers.

Brandeau and Chiu (1989) review 50 representative problems in location research and conclude that most of these problems are solved using optimization models.

Risk is involved in most operations and the management and understanding of risk is necessary. Nolz, Semet, and Doerner (2011) solve a multi-objective optimization problem for distribution of supplies in HA/DR operations. They focus on the risk involved in using transportation routes that become impassable after a disaster event. The research utilizes data from Manabi province, Ecuador.

## IV. MODEL METHODOLOGY

### A. MODEL SELECTION

The data collected indicates that multiple objectives should affect the decision of allocating CFS units to countries. The objectives considered are as follows:

- Aid provided to countries based on the severity of the natural disasters they suffer.
- Level of aid should be consistent with level of diplomatic relationship with the U.S.
- More aid should be provided to countries that have lower capabilities to aid themselves after disasters.
- Neighboring countries may be able to share aid depending on the severity of disasters.
- Total aid should not exceed budget limits.

In the context of supplying CFSMF system to countries that suffer natural disasters, the allocation decision of CFSMF systems to the various countries can be viewed as a multiple-objective optimization problem. Since the number of CFSMF systems allocated to a country must be an integer, the allocation model developed here is an integer programming (IP) optimization model. The various objectives are modeled here either as utilities (weights), or as bounds (constraints).

The utility of allocating a CFSMF system to a country can be estimated or evaluated in multiple ways. In this thesis, the utility measure used is a combination of the country's need and its relationship with the United States. More specifically,  $U_i$  - the utility parameter for country (i), is the sum of the percentage of persons affected by natural disasters in country (i), and the percentage of economic aid to country (i). These percentages are displayed in Table 3 and Table 4, respectively.

For example, the utility parameter for China is 0.5787, which is the sum of the percentage of persons affected by natural disasters in China (0.573), and the percentage of economic aid to China (0.0057).

Clearly, this method for utility parameter calculation can be much more sophisticated and include many more considerations at various levels of importance. A more sophisticated utility parameter calculation can be the responsibility of U.S. government agencies, such as the Department of State.

Table 3. Persons Affected in Each Country as a Percentage of the Total Persons Affected from the Sample Countries

Country	Persons Affected	%
China	1112214506	0.573
India	598790757	0.308
Bangladesh	71698450	0.037
Philippines	49768870	0.026
Thailand	28072184	0.014
Ethiopia	22831949	0.012
Vietnam	20316122	0.010
South Africa	15102150	0.008
Pakistan	12363793	0.006
Indonesia	10098137	0.005
Total	1941256918	1

Adapted from: Environmental indicators. (2010). Retrieved October 21, 2014 from <http://unstats.un.org/unsd/environment/qindicators.htm>

Table 4. Percentage of Economic Aid Received by Each Country as a Percentage of the Total Economic Aid Distributed Among the Sample Countries

Country	Aid (in millions)	%
China (P.R.C.)	151	0.0057
India	1607	0.0609
Bangladesh	1492	0.0565
Philippines	1771	0.0671

Country	Aid (in millions)	%
Thailand	278	0.0105
Ethiopia	6987	0.2646
Vietnam	0	0
South Africa	3503	0.1327
Pakistan	8121	0.3076
Indonesia	2493	0.0944
Total	26403	1

Adapted from: Greenbook. (n.d.). Retrieved April 3, 2015 from <https://explorer.usaid.gov/reports-greenbook.html>

## B. INTEGER PROGRAMMING MODEL

Decisions: Determine how many CFS units should be allocated to each country.

### 1. Decision Variables

$X_i$  = Number of CFS units to allocate to country (i)

i = 1(China), 2(India), 3(Bangladesh), 4(Philippines), 5(Thailand), 6(Ethiopia), 7(Vietnam), 8(South Africa), 9(Pakistan), 10(Indonesia)

### 2. Objective Function: Maximize the Total Allocation Utility Achieved

$$\sum_i U_i X_i \quad (1)$$

### 3. Constraints

Upper limit on total CFS units:

$$\sum_i X_i \leq 30 \quad (2)$$

Upper Limit of 2 on CFS Units to China:

$$X_1 \leq 2 \quad (3)$$

Upper Limit of 4 on CFS Units to every other country:

$$X_i \leq 4 \text{ for } i=2,3,\dots,10 \quad (4)$$

Upper Limit of 6 on combined CFS systems to the neighboring countries India and Pakistan:

$$X_2 + X_9 \leq 6 \quad (5)$$

*Non-negativity and Integrality:*

$$X_i \geq 0 \text{ and Integer} \quad (6)$$

Figure 5. Excel Solver Results.

China	India	Bangladesh	Philippines	Thailand	Ethiopia	Vietnam	S. Africa	Pakistan	Indonesia		
X1	X2	X3	X4	X5	X6	X7	X8	X9	X10		
2	4	4	4	2	4	0	4	2	4	6.122954464	
0.578654291	0.369319478	0.093442765	0.092713157	0.024989935	0.276390445	0.010465447	0.14045389	0.313947647	0.099622944	Allocation	Limits
1	1	1	1	1	1	1	1	1	1	30	30
1										2	2
	1									4	4
		1								4	4
			1		1					4	4
				1		1				2	4
					1		1			4	4
						1		1		0	4
							1			4	4
								1		2	4
									1	4	4
									1	6	6
	1										

#### 4. Results

After solving the problem using Excel Solver, the results are listed in Table 5:

Table 5. Number of CFS Systems Allocated to Each Country

Country	No. of Systems
China (P.R.C.)	2
India	4
Bangladesh	4
Philippines	4
Thailand	2
Ethiopia	4
Vietnam	0
South Africa	4
Pakistan	2
Indonesia	4

## V. CONCLUSION AND FURTHER RESEARCH

### A. CONCLUSIONS

The research of this paper focused on the optimal allocation of CFSMF to countries affected by natural disasters. Several factors were considered in the allocation model. The main two factors were the worldwide natural disaster events (climatological, geophysical, hydrological, and meteorological) for the 10-year period, 2000–2009 (“Environmental indicators,” 2010), and total economic aid obligated by USAID to foreign nations in the form of loans or grants (Greenbook, n.d.) for the 10-year period, 2003–2012. The raw data was sorted in descending order to obtain a ranking of countries based on number of persons affected by natural disasters over the 10-year period. The data was used in the integer programming optimization model to allocate a hypothetical number (30) of cold-formed steel mobile factory units to the countries with the most persons affected by natural disasters. To convert the total persons affected in each country to a percentage, the 10-year total persons affected in each country was divided by the 10-year total persons affected of the sample 10 countries that comprise persons affected (see Table 3). Similar steps were used to calculate the percentage of the total USAID economic aid obligated to each country in the 10-country sample (see Table 4). These percentages were added to achieve a utility parameter that represented the benefit to each country from each of the hypothetical 30 cold-formed steel mobile factory systems available for distribution by the United States.

In this optimization model, the objective was to maximize the total allocation utility of the cold-formed steel units. China, a country with a robust industrial base, had an upper limit of 2 CFSMF systems, as it is hypothesized that China has its own CFSMF systems, as well as sufficient means to aid displaced persons in the event of a natural disaster. All other countries (except India and Pakistan) were constrained to an upper limit of 4 CFSMF systems, whereas India and Pakistan’s constraint had a combined upper limit of 6 CFSMF systems. The reason for India and Pakistan having a combined upper limit of 6 is due to the two countries sharing a border and the assumption that, if needed, CFSMF systems can be transported between the two countries. This, of course, is

dependent on transportation routes being passable. The solution produced by Excel Solver is the recommendation to distribute the hypothetical 30 units to the 10 countries in the sample set.

## **B. RECOMMENDATIONS**

This study identifies the countries that are in most need of CFSMF based on persons affected and economic aid received and ultimately recommends the DOD purchase and maintain 20 CFSMF. These systems can be used by the DOD for HA/DR operations and the units will also be available for user training, DOD contingency operations, base support, training, or shipboard basing (Tully & Skidmore, 2015) among others.

The remaining 10 units will be purchased through USAID for NGOs that operate in the 10 countries identified. The NGOs will be able to use the units for HA/DR operations as well as for reinforcing the areas with sound structures to better prepare the communities in the event of another natural disaster strike.

## **C. AREAS FOR FURTHER RESEARCH**

Tully and Skidmore's (2015) analysis suggested that the cold-formed steel mobile factory systems could be a powerful asset in the humanitarian response to assist persons affected after natural disasters. Their evaluation of the operation of a CFSMF in an austere environment showed that the unit did have validity as part of the logistical response to a humanitarian disaster. Their evaluation was not conducted during an actual response to a disaster. However, it was conducted in an area that is susceptible to natural disasters. Further research of the performance of CFS systems during an actual response to a natural disaster is needed to determine if CFSMF can be a viable and integral part of disaster response. Results of this research can be used to determine the validity of a CFSMF for use by disaster aid organizations, military organizations, and governments, in order to assist displaced persons.

Another area for further research and testing includes identifying candidate areas for prepositioning of CFSMF systems. For example, several key areas of the world that

are prone to natural disaster events are located in Asia. In this case study 8 of the 10 countries identified from the UNSD (“Environmental indicators,” 2010) are in Asia. It is recommended that prepositioning sites be chosen such that handling heavy lift via aerial or seaports and adequate roads for easy transportation and distribution of the units are available.

Additional research will also be needed to determine an appropriate set of parameters for the model, requiring not only research into various countries’ capabilities, but also a political discussion regarding diplomatic relations and political preferences. As stated in this report, the case study provided here used simplistic, although partially supported by United Nations (UN) and USAID data, considerations.

Further research may also identify additional types of asset allocation decisions, such as allocation of emergency supply distribution centers, for which the proposed optimization model can be used. The model and the methodology described in this report can be utilized even if the discussed assets and the factors affecting the allocation decisions vary.

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## APPENDIX A. UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT RAW DATA

Table 6. USAID Foreign Economic Aid (Grants and Loans), 2003–2012

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Iraq	3782	7551	6292	4226	3693	3168	3082	1022	1142	784
Afghanistan	642	1433	1507	1352	1924	2696	2823	4498	2667	3326
Russia	695	879	1499	1386	1487	1372	478	439	904	339
Pakistan	322	349	434	629	616	532	1339	2002	759	1138
Sudan	188	477	884	757	806	1001	1214	890	524	298
Ethiopia	721	433	676	322	466	1004	960	989	552	865
Colombia	604	466	567	1112	161	677	717	684	286	544
Kenya	123	174	254	389	509	715	926	815	865	746
Jordan	1035	359	355	309	307	573	582	464	536	832
Haiti	83	162	224	210	206	306	371	1417	1198	510
West Bank/Gaza	191	134	347	85	152	519	1052	697	469	457
Egypt	412	653	232	443	634	187	593	367	172	103
Tanzania	80	97	133	187	237	1062	378	494	453	399
South Africa	78	128	185	260	391	566	568	563	490	273
Uganda	177	216	288	278	364	453	482	470	323	349
Nigeria	91	131	150	186	339	483	499	460	441	331
Mozambique	92	99	104	145	253	776	342	420	273	274
Indonesia	180	151	534	210	236	194	217	323	234	214
Congo (Kinshasa)	112	116	119	177	142	247	328	357	403	371
Israel	657	557	482	286	168	44	40	36	37	25
Zambia	66	100	142	191	203	263	298	338	287	222
Georgia	87	110	96	397	89	111	613	404	88	78
Mexico	53	83	92	168	72	83	431	624	335	118
Peru	254	252	171	305	107	150	146	194	133	102
Philippines	109	109	98	113	103	127	153	209	586	166
Ghana	74	71	71	104	608	89	127	210	150	209
Ukraine	88	126	152	141	165	119	178	304	209	207
Liberia	45	118	121	123	199	133	169	275	248	234
India	176	178	194	170	153	146	143	168	106	174
Bangladesh	102	89	78	82	88	184	168	237	217	247
Senegal	46	50	46	66	68	75	147	696	138	138
Mali	52	55	52	60	527	83	155	184	197	93
Bolivia	249	173	157	214	143	126	99	98	73	34
Zimbabwe	31	30	60	30	140	232	286	223	163	153
Somalia	31	31	41	103	82	305	180	64	202	275
Rwanda	47	59	75	104	121	172	175	230	159	155

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Lebanon	67	36	24	144	192	190	155	158	115	141
Malawi	39	55	80	73	101	105	142	213	209	153
Chad	7	59	60	82	97	127	223	174	151	157
Guatemala	82	70	64	104	81	108	143	165	153	130
Morocco	22	21	36	34	72	701	38	56	50	37
El Salvador	57	56	48	49	501	50	49	106	85	47
Namibia	31	31	49	64	91	132	395	105	71	67
Micronesia	100	95	94	100	100	79	108	90	135	97
Kazakhstan	61	72	62	109	90	112	92	162	90	76
Honduras	69	61	284	84	57	64	25	102	90	77
Armenia	79	72	69	315	73	68	60	77	47	-21
Angola	165	118	67	57	53	58	56	101	86	68
Nepal	52	50	70	61	79	106	87	82	106	121
Botswana	14	20	41	43	214	210	103	61	44	58
Burkina Faso	15	18	33	21	28	47	506	35	41	60
Cambodia	62	73	69	68	74	75	83	95	19	143
South Sudan									344	396
Yemen	39	58	16	36	25	32	57	125	79	237
Kosovo						209	138	176	100	76
Sri Lanka	28	36	153	47	40	71	85	122	81	26
Nicaragua	66	59	87	246	52	60	35	-14	66	26
Madagascar	47	45	155	53	63	65	55	59	74	66
Benin	30	29	25	23	327	39	45	56	50	37
Cote d'Ivoire	25	34	40	36	87	79	90	79	74	94
Moldova	41	46	31	25	49	24	32	307	31	29
China (P.R.C.)	28	38	40	46	57	100	63	97	87	60
Lesotho	3	5	4	4	44	365	30	46	45	27
Niger	14	20	25	34	38	50	44	131	79	134
Serbia and Montenegro	186	166	211	5						
Kyrgyzstan	55	39	43	36	37	50	52	114	60	77
Serbia				124	126	65	60	68	59	33
Mongolia	21	28	16	12	12	324	36	39	20	25
Dominican Republic	37	41	33	40	50	52	69	89	61	59
Marshall Islands	47	42	45	51	48	48	49	20	100	70
Azerbaijan	58	58	57	50	54	38	51	54	50	31
Burundi	44	49	59	49	37	47	65	54	53	44
Thailand	20	12	43	43	47	49	62	79	70	74
Ecuador	82	72	66	51	36	30	21	43	57	21
Tajikistan	48	49	54	39	31	43	49	74	36	37
Bosnia & Herzegovina	64	50	35	42	34	36	49	48	51	39

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Albania	42	52	39	49	31	44	35	37	33	31
Guinea	49	53	41	36	32	26	30	27	34	39
Uzbekistan	88	45	44	48	18	15	18	31	19	34
Korea, North	37	57	8	1	24	206	11	5	2	3
Macedonia	55	39	43	38	32	30	30	34	33	19
Brazil	40	24	46	37	20	35	43	33	44	21
Jamaica	24	39	62	34	32	21	26	36	33	17
Timor-Leste	24	19	26	25	29	34	36	46	27	37
Burma (Myanmar)	4	9	11	10	17	87	29	33	32	56
Poland	0	4	6	5	5	5	53	166	18	23
Eritrea	96	86	88	6	3	3	0	0	0	-1
Sierra Leone	42	33	27	21	18	11	26	37	25	21
Paraguay	13	18	13	52	16	15	56	36	21	16
Canada	24	21	21	23	24	27	26	26	27	23
Romania	40	40	47	36	19	13	10	11	9	9
Syria	0	0	0	3	8	44	19	22	26	107
Bulgaria	35	33	37	28	17	20	14	13	13	17
Palau	14	14	13	15	14	14	14	69	48	13
Libya		0	0	25	4	10	11	24	88	64
Guyana	10	20	23	21	31	30	23	19	17	9
Panama	17	21	18	27	24	12	28	34	11	9
Belarus	9	6	14	10	17	13	18	41	33	28
Swaziland	1	3	2	3	8	14	23	47	38	41
Mauritania	20	12	22	13	12	24	16	15	13	30
Cape Verde	6	7	9	119	3	5	6	4	7	9
Cameroon	16	13	13	10	6	20	24	22	20	31
Ireland	50		37		27		30	0	17	3
Cuba	8	9	15	18	12	34	21	17	15	11
Malaysia	1	0	3	2	5	51	38	34	17	9
Croatia	35	27	31	16	15	6	4	4	8	3
Tunisia	0	0	0	0	1	1	1	1	17	129
Turkey	8	10	16	5	13	12	15	23	14	21
China (Taiwan)	0	0	1	2	43	21	32	23	7	2
Djibouti	8	24	4	9	5	8	10	21	27	11
Central African Republic	1	2	2	4	21	18	22	19	18	22
Turkmenistan	9	8	7	10	14	15	12	19	10	12
Cyprus	1	4	36	8	14	17	10	16	9	1
Japan	0	0	1	0	0	4	1	1	94	4
Venezuela	10	12	9	10	8	19	6	11	5	9
Hungary	2	6	7	7	9	31	6	9	2	17
Vanuatu	2	2	2	70	4	4	4	2	3	2

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Czech Republic	1	2	3	10	30	6	7	19	12	4
Montenegro				15	11	12	10	16	13	4
Congo (Brazzaville)	5	6	2	14	11	3	5	18	5	13
Belgium		0	1		32	24	12	7	5	0
Algeria	3	3	2	3	4	12	11	15	10	11
Laos	7	5	5	3	3	7	7	15	13	8
Costa Rica	3	4	4	5	6	6	8	11	9	8
Guinea-Bissau	2	0	15	5	6	1	2	8	3	14
Latvia	1	2	2	6	11	7	4	3	12	4
Estonia	1	3	3	3	2	10	11	7	9	5
Argentina	1	2	1	2	8	3	3	6	18	6
Gambia, The	4	3	2	5	2	12	5	7	3	3
Chile	1	2	2	1	1	3	6	26	2	3
Oman		0	0	1	1	17	11	4	5	6
Togo	6	4	3	3	8	3	5	4	4	3
Spain			0		2	0	2	16	18	1
Lithuania	2	5	4	2	5	3	1	1	4	11
Bahamas, The	1	2	2	1	2	7	3	8	6	3
Iran	2	10	1	3	5	3	1	1	1	1
Slovakia	1	1	9	2	2	6	2	1	1	1
Korea, South	0		1	0	14	6	2	1	1	1
United Kingdom		0		0	20	2	1	1	1	1
Belize	2	2	2	2	2	2	3	5	2	2
Papua New Guinea		0	0	0	2	3	3	4	3	6
Gabon	3	3	2	1	1	0	1	1	2	5
Singapore		0	0	0	7	1	8	1	1	1
United Arab Emirates		0	1	1	11	1	1	1	3	0
Fiji	1	2	1	2	1	2	3	2	2	2
Portugal	0	0	0	0	0	1	10	3	1	0
Slovenia	0	1	4	1	3	1	2	2	1	0
Austria						6	4	3	1	0
Suriname	1	1	1	1	1	1	2	2	2	1
Samoa	1	1	1	1	1	1	1	2	1	1
Qatar	0		2	1	1	0	4	3	0	0
Sao Tome & Principe	0	1	0	0	0	9	0	0	0	0
Tonga	1	1	1	1	1	1	2	1	1	1
Saudi Arabia	0	0	1	2	1	1	1	1	2	2
Malta		0		1	1	0		0	5	1
Barbados	0	1	2	3	0	0	0	1	0	1
Bahrain	0	0	2	1	1	1	0	1	1	1

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Trinidad & Tobago	0	2	0	0	1	1	1	0	0	0
Kiribati	1	1	1	1	1	1	0	0	0	
Uruguay	0	1	1		1	1	1	1	1	1
China (Hong Kong)	1	0	0	0	0	0	1	2	0	1
Mauritius	0	0	1	0	1	0	0	0	1	0
France						2	0	2	1	0
Maldives			2		0	0	0	1	1	1
Greece			1	0		1	1	0	1	1
New Zealand					0	0	0	0	4	0
Kuwait			1	1	1	0	0	0		0
Italy			0	0	0	0	0	0	1	1
Sweden							0	0	1	3
Grenada	0	1	2	0	0	0	0	0	0	0
Netherlands					1	1	0	0	0	0
Solomon Islands	0	0	0	0	0	0	0	0	0	1
Comoros	0	0	0	0	0	1	0	1	0	0
Australia			0	0	0	0	0	0	0	1
Bhutan	1			0		0	0	0	0	1
Equatorial Guinea	0	0	0	0	0	0	0	0	0	0
Switzerland		0		0		0	0	0	0	
Seychelles	0	0	0	0	0	0	0	0	0	0
St. Vincent and Grenadines				0	0		0	0	0	
Antigua and Barbuda			0	0			0	0	0	0
Denmark							0	0		0
Norway			0			0	0		0	0
Dominica			0	0	0		0	0		
Brunei			0	0				0	0	0
Finland									0	
Germany			0			0	0	0		0
Iceland								0		0
St. Kitts and Nevis				0						
St. Lucia			0		0	0				0
Vietnam										

Adapted from: Greenbook. (n.d.). Retrieved April 3, 2015 from <https://explorer.usaid.gov/reports-greenbook.html>

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## APPENDIX B. UNITED NATIONS STATISTICS DIVISION RAW DATA

Table 7. Ten-Year Climatological Data

Country	No. of events	Persons affected	
		2000-2009	2000-2009
Afghanistan	6		4 960 000
Albania	3		150
Algeria	3		0
Angola	2		25 000
Antigua and Barbuda	0		0
Argentina	8		3 500
Armenia	1		297 000
Australia	12		16 754
Austria	3		0
Azerbaijan	1		0
Bangladesh	8		151 000
Belarus	2		0
Belgium	5		0
Belize	0		0
Benin	0		0
Bhutan	0		0
Bolivia	7		103 277
Bosnia and Herzegovina	5		72 575
Botswana	1		0
Brazil	7		2 000 000
Brunei Darussalam	0		0
Bulgaria	10		0
Burkina Faso	1		0
Burundi	3		2 232 500
Cambodia	3		1 550 000
Cameroon	2		0
Canada	5		1 800
Cape Verde	1		30 000
Central African Republic	1		0
Chad	1		800 000
Chile	6		25 000
China	19		254 664 000
China, Hong Kong SAR	0		0
Colombia	1		0
Comoros	0		0

Country	No. of events	Persons affected
Congo	0	0
Costa Rica	0	0
Cote d'Ivoire	0	0
Croatia	8	0
Cuba	2	0
Cyprus	4	0
Czech Republic	2	0
Dem. Rep. of the Congo	0	0
Denmark	0	0
Djibouti	4	632 750
Dominican Republic	1	0
Ecuador	0	0
Egypt	1	0
El Salvador	2	400 000
Eritrea	1	1 700 000
Estonia	1	0
Ethiopia	4	21 600 000
Fiji	0	0
France	8	3 000
Gambia	1	0
Georgia	1	696 000
Germany	5	0
Ghana	0	0
Greece	6	1 593
Guatemala	4	115 446
Guinea	1	0
Guinea-Bissau	2	132 000
Guyana	0	0
Haiti	1	35 000
Honduras	5	415 625
Hungary	5	0
India	18	350 000 000
Indonesia	5	15 000
Iran (Islamic Republic of)	1	0
Iraq	0	0
Israel	1	0
Italy	5	0
Jamaica	1	0
Japan	3	222
Jordan	2	150 000
Kazakhstan	1	0
Kenya	3	7 200 000

Country	No. of events	Persons affected
Kiribati	0	0
Korea, Republic of	4	3 800
Kyrgyzstan	1	0
Lao People's Dem. Rep.	0	0
Latvia	3	0
Lebanon	1	0
Lesotho	2	975 000
Liberia	0	0
Lithuania	2	0
Luxembourg	1	0
Madagascar	3	845 290
Malawi	3	8 449 435
Malaysia	1	0
Mali	3	1 025 000
Mauritania	1	1 000 000
Mauritius	0	0
Mexico	6	0
Micronesia, Federated States of	0	0
Mongolia	1	450 000
Morocco	1	0
Mozambique	7	3 239 500
Myanmar	0	0
Namibia	2	345 000
Nepal	3	200 000
Netherlands	4	0
New Zealand	1	0
Nicaragua	3	204 000
Niger	2	6 584 558
Nigeria	1	0
Pakistan	7	0
Panama	1	1 436
Papua New Guinea	0	0
Paraguay	6	380 990
Peru	6	3 083 427
Philippines	2	0
Poland	5	0
Portugal	8	150 000
Puerto Rico	0	0
Republic of Moldova	3	210 394
Romania	11	0
Russian Federation	21	1 031 000

Country	No. of events	Persons affected
Rwanda	1	1 000 000
Samoa	0	0
Sao Tome and Principe	0	0
Senegal	1	284 000
Serbia	2	0
Slovakia	4	0
Slovenia	1	0
Solomon Islands	0	0
Somalia	4	4 700 000
South Africa	8	15 001 000
Spain	9	1 200
Sri Lanka	1	1 000 000
Sudan	1	2 000 000
Swaziland	3	1 381 500
Sweden	1	0
Switzerland	3	0
Syrian Arab Republic	1	1 000 000
Tajikistan	3	5 800 000
Thailand	4	15 000 000
The Former Yugoslav Rep. of Macedonia	5	1 000 202
Timor-Leste	1	0
Togo	0	0
Tunisia	0	0
Turkey	8	0
Uganda	3	2 005 000
Ukraine	3	50 000
United Kingdom	3	0
United Rep. of Tanzania	2	2 154 000
United States	46	786 526
Uruguay	3	2 400
Uzbekistan	1	600 000
Viet Nam	3	1 710 000
Zambia	1	1 200 000
Zimbabwe	2	8 100 000

Adapted from: Climatological disasters, 2010. Retrieved October 21, 2014, from [http://unstats.un.org/unsd/environment/Climatological\\_disasters.htm](http://unstats.un.org/unsd/environment/Climatological_disasters.htm)

Table 8. Ten-Year Geophysical Data

Country	No. of events	Persons affected
		2000-2009
Afghanistan	12	90 740
Albania	1	0
Algeria	5	160
American Samoa	1	2 500
Argentina	2	500
Armenia	0	0
Australia	0	0
Austria	0	0
Azerbaijan	1	2 694
Bangladesh	3	3 500
Barbados	1	0
Belgium	0	0
Bhutan	1	0
Bolivia	0	0
Brazil	1	280
Bulgaria	1	525
Burundi	1	0
Cameroon	0	0
Cape Verde	0	0
Chile	4	60 463
China	48	52 742 377
Colombia	13	146 967
Comoros	3	284 000
Congo	1	0
Costa Rica	3	128 842
Croatia	0	0
Cuba	0	0
Cyprus	0	0
Dem. Rep. of the Congo	3	17 355
Dominica	1	100
Dominican Republic	1	2 000
Ecuador	7	497 670
Egypt	2	250
El Salvador	5	1 601 648
Ethiopia	2	11 000
Fiji	0	0
France	0	0
Georgia	2	25 300
Germany	1	150

Country	No. of events	Persons affected
Greece	5	4 518
Guadeloupe	1	100
Guam	0	0
Guatemala	4	2 987
Guinea	0	0
Honduras	3	51 720
Iceland	2	129
India	4	5 012 599
Indonesia	49	6 412 196
Iran (Islamic Republic of)	24	660 787
Iraq	0	0
Italy	6	230
Japan	17	154 949
Kazakhstan	1	36 000
Kenya	1	0
Kyrgyzstan	3	15 000
Lebanon	0	0
Liberia	0	0
Malawi	2	0
Malaysia	1	0
Maldives	1	12 000
Martinique	1	0
Mexico	4	218 830
Montserrat	1	200
Morocco	1	0
Mozambique	1	0
Myanmar	1	12 500
Nepal	0	0
Netherlands	0	0
New Zealand	0	0
Nicaragua	1	1 785
Pakistan	6	1 151 699
Panama	2	1 000
Papua New Guinea	11	45 299
Peru	7	888 911
Philippines	9	330 400
Poland	0	0
Romania	0	0
Russian Federation	6	17 273
Rwanda	2	1 535

Country	No. of events	Persons affected
Saint Lucia	1	0
Samoa	1	5 275
Seychelles	1	4 760
Slovenia	1	600
Solomon Islands	1	2 375
Somalia	1	104 800
South Africa	1	0
Spain	0	0
Sri Lanka	1	516 130
Sudan	0	0
Tajikistan	6	29 588
Thailand	1	58 550
Tonga	1	500
Trinidad and Tobago	0	0
Turkey	15	531 460
Turkmenistan	1	0
Uganda	0	0
United Kingdom	1	4 500
United Rep. of Tanzania	5	5 750
United States	6	30 619
Uzbekistan	0	0
Vanuatu	7	19900
Venezuela (Bolivarian Republic of)	0	0
Wallis and Futuna Islands	0	0
Yemen	1	0

Adapted from: Geophysical Disasters. (2010). Retrieved October 21, 2014, from [http://unstats.un.org/unsd/environment/Geophysical\\_disasters.htm](http://unstats.un.org/unsd/environment/Geophysical_disasters.htm)

Table 9. Ten-Year Hydrological Data

Country	No. of events	Persons
		affected
	<b>2000-2009</b>	<b>2000-2009</b>
Afghanistan	45	435 796
Albania	4	80 884
Algeria	25	195 300
American Samoa	1	0
Angola	21	783 328
Anguilla	0	0
Argentina	20	707 610
Armenia	1	0
Australia	21	35 360
Austria	7	61 416
Azerbaijan	3	35 000
Bahamas	0	0
Bangladesh	23	58 601 793
Barbados	0	0
Belarus	0	0
Belgium	6	2 610
Belize	1	38 000
Benin	4	287 884
Bhutan	2	0
Bolivia	13	1 431 485
Bosnia and Herzegovina	7	294 230
Botswana	4	116 392
Brazil	39	4 055 552
Bulgaria	11	13 260
Burkina Faso	8	259 640
Burundi	16	28 965
Cambodia	8	6 644 182
Cameroon	6	24 500
Canada	18	16 070
Cape Verde	1	0
Central African Republic	6	6 000
Chad	8	363 883
Chile	14	641 570
China	124	525 648 482

Country	No. of events	Persons affected
China, Hong Kong SAR	1	0
Colombia	34	4 488 763
Comoros	1	2 500
Congo	4	25 000
Costa Rica	14	284 189
Cote d'Ivoire	3	2 450
Croatia	4	2 050
Cuba	6	75 775
Czech Republic	6	218 765
Dem. Rep. of the Congo	12	31 370
Djibouti	1	98 500
Dominican Republic	9	110 965
Ecuador	11	413 630
Egypt	2	800
El Salvador	8	7 332
Eritrea	2	7 000
Ethiopia	24	1 220 949
Fiji	7	12 280
Finland	1	400
France	18	53 661
French Guiana	0	0
French Polynesia	0	0
Gabon	0	0
Gambia	4	14 808
Georgia	4	3 100
Germany	6	331 450
Ghana	7	691 345
Greece	14	12 180
Guadeloupe	0	0
Guatemala	14	314 356
Guinea	5	286 085
Guinea-Bissau	3	0
Guyana	4	409 774
Haiti	20	355 119
Honduras	9	334 275

Country	No. of events	Persons affected
Hungary	8	45 814
Iceland	0	0
India	109	238 302 253
Indonesia	88	3 685 941
Iran (Islamic Republic of)	22	1 412 850
Iraq	5	70 890
Ireland	2	300
Israel	0	0
Italy	17	58 000
Jamaica	2	30 000
Japan	12	455 028
Jordan	0	0
Kazakhstan	5	44 168
Kenya	30	1 246 738
Kiribati	1	0
Korea, Dem. People's Rep.	9	1 203 630
Korea, Republic of	11	337 831
Kuwait	0	0
Kyrgyzstan	7	1 481
Lao People's Dem. Rep.	5	1 257 190
Lebanon	1	17 000
Lesotho	0	0
Liberia	3	17 584
Libyan Arab Jamahiriya	0	0
Lithuania	1	0
Luxembourg	0	0
Madagascar	4	111 488
Malawi	15	1 159 276
Malaysia	24	369 564
Maldives	1	1 649
Mali	11	89 071
Marshall Islands	1	600
Mauritania	9	98 120
Mexico	28	1 893 220

Country	No. of events	Persons affected
Micronesia, Federated States of	1	0
Mongolia	3	15 500
Montenegro	2	1 536
Morocco	12	57 850
Mozambique	15	6 212 111
Myanmar	9	223 668
Namibia	9	474 300
Nepal	16	2 277 432
Netherlands	0	0
New Zealand	6	6 850
Nicaragua	8	66 866
Niger	7	222 549
Nigeria	28	532 865
Norway	2	2 100
Occupied Palestinian Territory	1	0
Pakistan	41	9 562 094
Panama	15	89 097
Papua New Guinea	11	89 256
Paraguay	2	14 800
Peru	20	659 997
Philippines	51	4 319 639
Poland	5	19 850
Portugal	5	348
Puerto Rico	3	11 705
Republic of Moldova	3	11 000
Romania	32	202 778
Russian Federation	32	872 104
Rwanda	8	40 795
Saint Kitts and Nevis	0	0
Saint Lucia	0	0
Samoa	1	0
Saudi Arabia	7	13 450
Senegal	7	523 177
Serbia	2	15 580
Seychelles	0	0

Country	No. of events	Persons affected
Sierra Leone	4	20 955
Slovakia	6	330
Slovenia	1	0
Solomon Islands	2	7 000
Somalia	19	713 550
South Africa	14	118 116
Spain	8	6 030
Sri Lanka	17	3 737 043
St. Vincent and the Grenadines	0	0
Sudan	13	1 408 246
Suriname	2	31 548
Swaziland	2	274 500
Sweden	0	0
Switzerland	6	7 381
Syrian Arab Republic	2	0
Tajikistan	21	470 664
Thailand	33	13 013 634
The Former Yugoslav Rep. of Macedonia	6	109 750
Timor-Leste	5	4 505
Togo	4	174 615
Trinidad and Tobago	1	1 200
Tunisia	5	33 500
Turkey	22	111 476
Turkmenistan	0	0
Uganda	14	489 066
Ukraine	6	538 665
United Kingdom	15	350 830
United Rep. of Tanzania	12	71 248
United States	57	11 317 806
Uruguay	7	142 200
Uzbekistan	1	1 500
Vanuatu	2	3 950

Country	No. of events	Persons affected
Venezuela (Bolivarian Republic of)	12	128 421
Viet Nam	41	10 961 710
Yemen	16	28075
Zambia	11	3013620
Zimbabwe	5	265 000

Adapted from: Hydrological disasters. (2010). Retrieved October 21, 2014, from [http://unstats.un.org/unsd/environment/Hydro\\_disasters.htm](http://unstats.un.org/unsd/environment/Hydro_disasters.htm)

Table 10. Ten-Year Meteorological Data

Country	No. of events 2000-2009	Persons affected 2000-2009
Afghanistan	4	193 158
Albania	2	525 000
Algeria	3	0
American Samoa	2	20 000
Anguilla	0	0
Antigua and Barbuda	1	25 800
Argentina	8	6 400
Australia	26	35 665
Austria	6	300
Bahamas	8	20 500
Bangladesh	40	13 096 657
Barbados	2	0
Belarus	1	0
Belgium	3	0
Belize	7	112 000
Benin	1	800
Bermuda	1	0
Bhutan	1	0
Bolivia	2	18 740
Bosnia and Herzegovina	1	0
Botswana	1	400
Brazil	5	151 850
British Virgin Islands	0	0

Country	No. of events	Persons affected
Bulgaria	2	0
Burundi	3	0
Cambodia	2	178 000
Canada	11	500
Cape Verde	0	0
Cayman Islands	7	300
Central African Republic	3	9 137
Chad	1	0
Chile	2	2 112
China	85	279 159 647
China, Hong Kong SAR	6	3 800
China, Macao SAR	0	0
Colombia	2	3 074
Comoros	1	0
Cook Islands	2	1 344
Costa Rica	3	56 074
Croatia	1	0
Cuba	14	9 721 908
Cyprus	2	0
Czech Republic	6	0
Dem. Rep. of the Congo	5	75 000
Denmark	3	0
Djibouti	0	0
Dominica	2	7 675
Dominican Republic	12	185 183
Egypt	1	0
El Salvador	6	150 541
Eritrea	0	0
Estonia	1	100
Fiji	8	39 082
Finland	0	0
France	17	4 150
French Polynesia	0	0

Country	No. of events	Persons affected
Gabon	1	0
Gambia	4	16 675
Georgia	1	900
Germany	16	0
Greece	4	600
Grenada	2	61 650
Guadeloupe	1	0
Guam	4	10 544
Guatemala	5	486 768
Guinea	1	0
Guinea-Bissau	0	0
Haiti	18	706 756
Honduras	7	184 420
Hungary	3	0
India	29	5 475 905
Indonesia	2	3 715
Iran (Islamic Republic of)	5	170 500
Ireland	4	200
Israel	1	410
Italy	3	0
Jamaica	12	398 016
Japan	34	966 641
Jordan	2	0
Kazakhstan	0	0
Kenya	0	0
Korea, Dem. People's Rep.	3	487401
Korea, Republic of	15	154 725
Kyrgyzstan	1	9 075
Lao People's Dem. Rep.	1	128 796
Latvia	2	0
Lebanon	1	500
Lesotho	3	5 500
Liberia	1	0
Lithuania	1	0
Luxembourg	0	0
Madagascar	22	3 193 291
Malawi	1	0

Country	No. of events	Persons affected
Malaysia	4	41 655
Maldives	0	0
Marshall Islands	0	0
Martinique	1	0
Mauritania	0	0
Mauritius	2	0
Mexico	27	4 279 471
Micronesia, Federated States of	4	7 300
Mongolia	6	1 911 000
Montserrat	0	0
Morocco	1	0
Mozambique	9	351 650
Myanmar	3	2 460 075
Nepal	0	0
Netherlands	4	0
Netherlands Antilles	0	0
New Caledonia	1	0
New Zealand	4	400
Nicaragua	10	269 379
Niger	1	1 250
Nigeria	1	0
Niue	1	200
Northern Mariana Islands	1	0
Norway	2	0
Oman	3	20 050
Pakistan	5	1 650 000
Panama	0	0
Papua New Guinea	1	162 140
Paraguay	3	48 355
Peru	1	86 682
Philippines	81	45 118 831
Poland	8	1 050
Portugal	1	0
Puerto Rico	4	3 500

Country	No. of events	Persons affected
Republic of Moldova	1	2 600 000
Réunion	3	0
Romania	6	2 490
Russian Federation	12	18 000
Saint Helena	1	300
Saint Kitts and Nevis	0	0
Saint Lucia	2	0
Samoa	2	0
Saudi Arabia	0	0
Senegal	1	0
Seychelles	1	6 800
Sierra Leone	0	0
Slovakia	1	10 300
Slovenia	2	0
Solomon Islands	3	275
Somalia	0	0
South Africa	11	101 150
Spain	5	0
Sri Lanka	2	425 000
St. Vincent and the Grenadines	2	1 000
Sudan	1	0
Swaziland	2	7 425
Sweden	2	0
Switzerland	6	0
Syrian Arab Republic	2	0
Tajikistan	1	830
Thailand	11	85 869
The Former Yugoslav Rep. of Macedonia	1	0
Timor-Leste	1	8 730
Tokelau	1	0
Tonga	2	16 500

Country	No. of events	Persons affected
Trinidad and Tobago	2	560
Turkey	5	1 500
Turks and Caicos Islands	4	1 700
Tuvalu	0	0
Uganda	3	0
Ukraine	5	53 668
United Kingdom	9	23 280
United Rep. of Tanzania	3	1 275
United States	129	8 598 206
United States Virgin Islands	1	0
Uruguay	3	1 300
Vanuatu	3	54 505
Venezuela (Bolivarian Republic of)	1	1 645
Viet Nam	33	7 644 412
Wallis and Futuna Islands	0	0
Yemen	2	0
Zimbabwe	2	0

Adapted from: Meteorological disasters. (2010). Retrieved October 21, 2014, from [http://unstats.un.org/unsd/environment/Meteo\\_disasters.htm](http://unstats.un.org/unsd/environment/Meteo_disasters.htm)

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